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USING FIRE MODELS TO ESTABLISH PERFORMANCE REQUIREMENTS FOR THE DESIGN OF BUILDINGS

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ABSTRACT

Based on continuing research into fire phenomena, the General Services Administration (GSA) has developed a methodology for assessing building fire safety. Fire modeling together with product test data is used to identify fire safety risks and develop corrective actions. This methodology gives GSA the ability to develop performance-based fire protection requirements for each of its buildings. This paper describes recent cooperative work between GSA and the National Institute of Standards and Technology to enhance the GSA Fire Risk Assessment methodology. Efforts to develop a procedure for using small scale test data in place of full or medium scale tests are discussed. In addition, an actual fire experience is used to illustrate the successful application of the methodology.

INTRODUCTION

The General Services Administration (GSA) is the business agent for the United States Government. It is responsible for the acquisition and management of everything from pencils to buildings. Within GSA, the Public Buildings Service (PBS) operates as the federal government's real property manager. In this capacity, PBS is responsible for the acquisition, design, construction, and operation and management of various types of space for federal agencies

Currently, the inventory of space includes 1700 Government owned buildings and 5100 leased locations. This represents approximately 28 million square meters of space. A number of historic buildings are included in the multitude of buildings controlled by GSA. GSA real estate leasing policy gives preferential treatment to historic buildings. A recent survey of buildings indicated the oldest building in the inventory was 180 years old.

GSA is responsible for ensuring the fire and life safety of the employees and visitors occupying the space under its control. In addition, GSA must protect federal real and personal property assets, assure continuity in the mission of occupant agencies, and provide safeguards for emergency forces if an incident occurs. Within PBS, the Office of Property Management develops the methodologies and procedures used for evaluating the safety of government occupied buildings and coordinating implementation by the GSA regional offices throughout the nation.

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EQUIVALENCY CONCEPTS

Traditionally, the design of building fire safety in the United States has relied on building or fire safety code compliance. Conformance of individual building elements to specific code requirements is assumed to yield an adequate level of safety. While prescriptive-based codes are easier to enforce, design flexibility and innovation are limited severely. Typically, new code requirements are added after a disaster to prevent recurrence. Since only individual components of the total building fire safety system are addressed, the entire system never is evaluated to determine the need for previously instituted code requirements. This means that building fire protection features require an ever increasing portion of the construction budget with possibly little or no increase in safety.

In partial recognition of this, most building and fire safety codes contain equivalency clauses. These clauses permit the use of alternative methods and materials when their equivalency can be proven to the *authority having jurisdiction*. In the past, subjective judgement formed the basis for determining equivalency. Continuing research into fire phenomena has made it possible to perform an engineering analysis of the fire safety performance of a building. This building could differ widely from current perceptions of a code conforming building. Using analytical engineering tools, the development and impact of fire in a building can be assessed. Recommended improvements can be prioritized based on their predicted impact on the risks associated with potential fire exposure.

The United States Congress included an equivalency option in the Federal Fire Safety Act. This Act, passed by Congress and signed by President George Bush in 1992, is part of the Fire Administration Authorization Act (Public Law 102-522). The Federal Fire Safety Act requires sprinklers or an *equivalent level of safety* in all new six story or higher Federal Employee Office Buildings, and during renovations of such buildings if they are six stories or higher and the renovation is more than 50 percent of the value of the structure. In addition, when the Government leases 3,250 total aggregate square meters or more of space and any portion is on or above the sixth floor, the entire building must be protected with sprinklers or an *equivalent level of safety*. A "Federal Employee Office Building" is defined as any building, owned or leased by the Federal Government, that can be expected to house at least 25 Federal employees during the course of their employment.

The General Services Administration was required by the Act to issue regulations further defining the term *equivalent level of safety*. In developing the regulations, GSA held meetings with a working group composed of representatives from the United States Fire Administration, the National Institute of Standards and Technology, and the Department of Defense as well as a number of other affected federal agencies, trade associations, state fire marshals, fire chiefs, consulting engineering firms, building owners, academia, and research institutions. The final regulation was established in the form of a performance requirement[1]. A fire protection engineering analysis is used to measure hazard and the amount of protection provided by the building. The concept for the final rule was derived from GSA fire protection program philosophy and built upon the equivalency concept contained in building and fire safety codes.

RISK MANAGEMENT

Typically, government agencies in the United States do not have insurance like private sector building owners or occupants. Any loss that occurs must be paid out of an agency's operating budget. A single loss could severely impact an agency's ability to conduct nationwide operations. Building and fire codes are intended to protect against loss of life and limit fire impact on the community. These codes do not necessarily protect the assets of the building owner or occupant. Simple code compliance does not ensure a level of safety acceptable to the building owner or occupant. The continual search for code compliance is not sufficient justification for resource allocation.

With cost effectiveness in mind, the GSA fire protection program addresses all aspects of fire safety important to a building owner or occupant (life safety, property protection, and mission continuity). To ensure adequate levels of safety, the relationship between expenditures on fire safety and the actual impact of these expenditures is examined through technical analysis. Each building in the GSA inventory is subjected to a fire safety analysis every five years These building surveys are conducted by fire protection engineering professionals.

A critical step in the evaluation of a building's fire safety performance is identification of a set of design fires. These fires are ones that could produce severe affects on the building and its occupants. Full scale testing of fuel packages, analysis of fire loss statistics, and professional judgment are used to establish the set of design fires. Using the design fires and building characteristics, potential fire scenarios are modeled to determine the effects on life safety, property, and mission. Based on this professional analysis, actual risk conditions in each building are identified and corrective actions recommended. As necessary, building owners allocate resources to abate significant risks.

RESEARCH ACTIVITIES

In support of its risk management philosophy, GSA has sought to look beyond the codes and standards for methods that would allow technical assessment of building fire safety risks and development of necessary solutions. GSA professional staff have been involved in the development of various alternative methods of analyzing life safety such as system concepts[2] and National Fire Protection Association Standard 101A, *Alternative Approaches to Life Safety*[3].

In addition, significant resources have been devoted to the development of life safety alternatives through scientific research. GSA has focused its research activities in three major areas: model development and verification, suppression system effectiveness, and protection of mobility impaired persons. The development of *FPETool*[4,5] was a significant result of these research activities.

GSA initiated development of a Fire Protection, Facility Assessment and Risk Analysis Methodology (*FPETool*) at the Center for Fire Research at the National Bureau of Standards, now the Building and Fire Research Laboratory at the National Institute of Standards and

Technology, in the late 1980's. The first official release of *FPETool* occurred in early 1991. Using this package of analytical engineering tools, the development and impact of fire in a building can be assessed. GSA has integrated the use of *FPETool* into its design review and facility assessment processes for evaluation of fire risk in GSA controlled space and appropriate resource allocation.

GSA is continuing to fund efforts to enhance and validate *FPETool*. Recently, the National Institute of Standards and Technology developed a sprinkler fire suppression algorithm[6] for *FPETool*. As part of this effort, fuel packages consisting of office furnishings and equipment were selected and burned to determine their heat release rate characteristics with and without fire suppression. All of the furniture fuel packages were ignited with a 50 kW natural gas burner which simulated a small trash can fire.

The primary fuel packages used in the tests fell into four categories: 1) reception area furnishings, 2) office furnishings, 3) workstations and 4) maintenance carts. These "typical" fuel packages had been identified during a physical survey of furnishings at the GSA Central Office in Washington DC. Of the four fuel package categories, the workstation fuel package category produced the widest range of heat release rates and the highest peak heat release rates. The workstations were composed of partitions and laminated wood composite work surfaces with metal support structures. A plastic "tub chair", a computer terminal, and a paper product load of 98 kg completed each of the workstation fuel packages.

For a workstation composed of 2 partitions, forming a corner around the work surface, a peak heat release rate of 1,700 kilowatts (kW) or 1.7 megawatts (MW) was attained at approximately 300 seconds after ignition. A workstation enclosed by partitions on three sides, produced a peak heat release rate of 6.7 MW at approximately 9 minutes after ignition. The fire in the three sided workstation developed slowly until it reached a plateau at approximately 1 MW. Shortly thereafter, the fire rapidly filled the confines of the workstation in a manner similar to that of a flashover.

As a result of this work, additional full scale testing is being conducted to evaluate whether materials or geometry is the dominate phenomena in the observed behavior. A representative cross section of commercially available workstations was selected and is being tested in two, three, and four sided configurations under a large calorimeter. Cone calorimeter[7] and LIFT[8] tests are also being conducted on appropriate size samples of the partition and furnishing materials. Finally, a single type of workstation is being used for a set of three multiple workstation fire tests using no suppression, quick response pendant sprinklers, and quick response sidewall sprinklers, respectively. For each test, three workstations are placed in a large compartment (6 m x 6 m x 3 m) which has one wall open to simulate the effects of a typical open plan office space.

In addition to enhancing the understanding of fire growth, this study is intended to evaluate alternatives to the tunnel test (ASTM E 84) and current GSA flame spread requirements. GSA specifies workstation fire performance characteristics based on results obtained from the tunnel test. The data obtained from the full scale test series will be used to expand the GSA catalog of product heat release rate data. This data is vital in applying fire modeling techniques to the assessment of fire hazard. In addition, the sprinklered heat release rate data will be useful in demonstrating the effectiveness of sprinkler systems in mitigating potential fire and smoke hazards and verifying the sprinkler fire suppression algorithm in *FPETool.*

GSA research activities have resulted in a number of additions to the *FPETool* suite of programs. The *FPETool* Version 3.2 includes a sprinkler suppression module, a routine to calculate smoke flow down a corridor[9], and a model of smoke and toxic gas intrusion into a room. In addition, significant efforts have been directed at developing data for verification and validation of the model and its components[10,11].

Several projects have been completed or are underway to examine the impact of sprinkler response characteristics and sprinkler head placement on activation time. GSA is participating in the National Fire Protection Research Foundation study to analyze sprinkler and heat detector placement under obstructed and sloped ceilings[12]. This study utilizes computational fluid dynamics models to calculate three dimensional flow fields near detector sensing elements. Other projects include analysis of quick response sprinklers in open plan office space[13], assessment of the impact of recessed sprinkler installation on activation time, investigation into sidewall sprinklers in open plan office space, and development of methods for installation of sprinklers in buildings with asbestos fireproofing[14].

Finally, a number of issues associated with developing and assessing the effectiveness of various strategies for protecting disabled persons have been addressed. Some specific topic areas include evaluation of staging areas for the disabled[15], analysis of fire evacuation by elevators[16], and investigation into post flashover fire gas exposure to corridors and adjoining refuge areas[17,18]. The latter project included assessment of both sprinklered and unsprinklered scenarios.

APPLICATION

Currently, research efforts are being used in GSA construction standards to supplement the national codes. Legally, buildings built on federal property are exempt from local building codes. However, buildings developed on private land for lease by the federal government are subject to applicable local codes. Through active involvement in various national consensus standards making bodies, information obtained through research is being translated into practical applications. As a developer, owner, and operator of buildings, GSA's unique position enables it to rapidly implement new technologies providing equivalent or better protection at reduced cost.

GSA developed its Fire Risk Assessment methodology as part of an effort to provide engineers with the tools necessary to scientifically evaluate fire safety risks. The methodology has been used to evaluate a number of buildings including several historic buildings: the Danville Post Office-Courthouse[19], the Klingle Mansion[20], the Department of Commerce headquarters building, and the Department of Interior headquarters building. Recently, the effectiveness of the methodology was demonstrated through an actual fire incident in the Department of Interior building.

The Department of Interior building, constructed in the late 1920's, is an eight story granite and limestone structure occupying two square blocks in northwest Washington, DC (see Figure 1). Floor slabs and columns supporting the structure are made of reinforced concrete. Typical office space, measuring 5.8 m x 3.9 m x 3.3 m, is constructed of 0.1 m thick terra cotta walls and finished with plaster and metal partitions. The offices have fuel loads typical of business occupancies including desks, tables, chairs, paper, and electronic office equipment. Offices are located in twelve wings which join a main corridor at one common end. Six wings extend from each of the long sides of the main corridor. A typical wing is at least 41 m long, 2 m wide, and 3 m high. The means of egress from each of these wings is stairs located in the central corridor. The building contains decorative asbestos acoustical ceiling material and original wiring, installed in 1934.

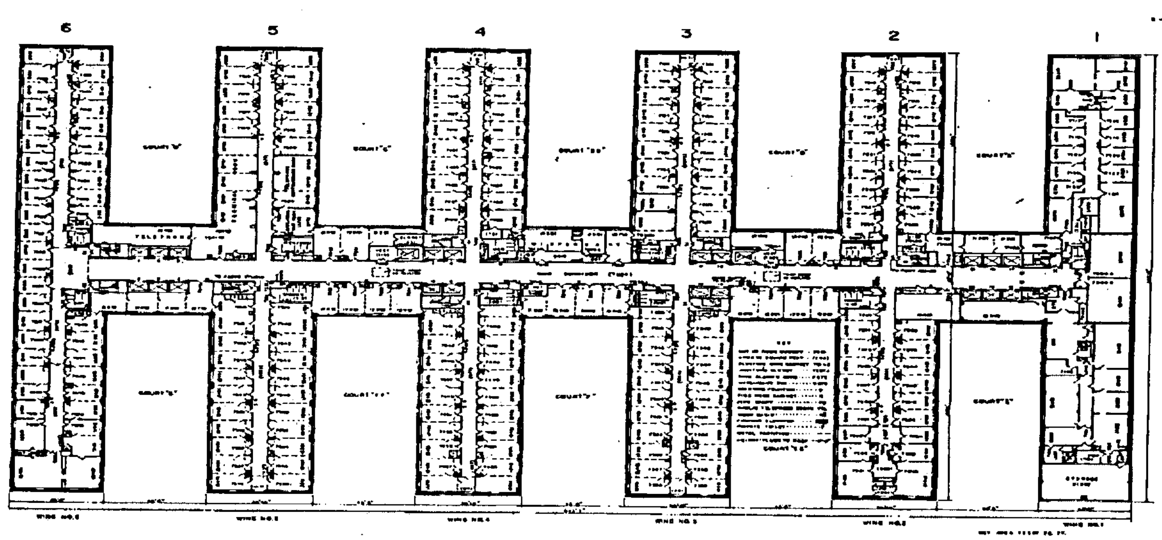

Fig. 1. Department of Interior Building - Typical Floor Plan

The potential impact of a fire in the Department of Interior building was analyzed using *FPETool* and the GSA Fire Risk Assessment methodology. Based on the results of this analysis, a recommendation was made and implemented to install a temporary sprinkler system in the building. This system was installed exposed, under the ceiling using mostly quick response, extended coverage sidewall sprinklers. The system covered approximately 85 percent of the floor area in the building. On December 26, 1993, as installation of the temporary system was being completed, a fire occurred in the building. The sprinkler system activated, controlling the fire and limiting fire damage to the workstation of origin. If the sprinkler system had not been in place, significant fire damage would have occurred in at least one wing of the building. Smoke damage would have extended throughout the floor on which the fire occurred, and some smoke would have spread to the upper floors of the involved wing. It would probably have been necessary to close parts of the building for several days while cleanup and restoration efforts were underway.

INNOVATION INCREASES SAFETY

Through the use of the Fire Risk Assessment Methodology and *FPETool*, GSA is implementing a performance-based system of building design and assessment. This methodology enables GSA to rapidly apply the knowledge gained from its research activities in practical applications.

The National Institute of Standards and Technology and GSA continue to work together to expand the science of fire protection. Optimal utilization of sprinklers is a key component in most fire protection strategies. Efforts are underway to further evaluate sprinkler response and improve their application.

In order to use most fire models like *FPETool*, heat release rate data must be available. A catalog of heat release rates for typical office furnishings is being developed. In addition to the data required by the models, this catalog will include video footage of the fire tests and still pictures of the tested items. Finally, validation of the *FPETool* fire model and its subcomponents is an on-going effort.

Significant advances in the scientific understanding of fire have occurred over the last several years. These advances have resulted in the development of a number of engineering tools for measuring building fire performance. However, the application of these tools remains limited because there is no widely accepted framework in which to apply these tools. Building and fire codes simply state that equivalency based on performance is possible without giving any guidance on how it is to be judged.

Currently, work is underway to develop a framework in which to utilize performance-based equivalency. The results of this effort will foster the application and acceptance of fire protection engineering analysis tools. By designing to meet the expected fire challenge and not the specific code book requirements, the overall level of fire safety in buildings can be increased.

REFERENCE LIST

[1] 41 CFR Subpart 101-6.6 Fire Protection (Firesafety) Engineering, Federal Register, Vol 59, No. 210, November 1, 1994, pp. 54524-54532.

[2] Nelson, H. E., *The Application of Systems Analysis to Building Firesafety Design*, Canadian Structural Engineering Conference, 1974.

[3] *Alternative Approaches to Life Safety*, National Fire Protection Association Standard 101A, National Fire Protection Association, Quincy, MA.

[4] Nelson, H. E., *FPETool: Fire Protection Engineering Tools for Hazard Estimation*, NISTIR 4380, National Institute of Standards and Technology, October 1990.

[5] Nelson, H. E., *FPETool Users Guide*, NISTIR 4439, National Institute of Standards and Technology, October 1990.

[6] Madrzykowski, D. and Vettori, R. L., *A Sprinkler Fire Suppression Algorithm*, Journal of Fire Protection Engineering, Vol. 4, No. 4, Society of Fire Protection Engineers.

[7] Babrauskas, V., *Development of the Cone Calorimeter - A Bench Scale Heat Release Rate Apparatus Based on Oxygen Consumption*, Fire and Materials, 8, 81-95, 1984.

[8] Quintiere, J. G., and Harkleroad, M. T., *New Concepts for Measuring Flame Spread Properties*, pp. 239-267 in Fire Safety Science and Engineering (ASTM STP 822), American Society for Testing and Materials, Philadelphia, PA, 1985.

[9] Nelson, H.E. and Deal, S., *A Routine for Estimating the Initial Wave Front Resulting from High Temperature Fire Exposure to a Corridor*, NISTIR 4869, National Institute of Standards and Technology, July 1992.

[10] Walton, W.D. and Notarianni, K.A., *A Comparison of Ceiling Jet Temperatures Measured in an Aircraft Hanger Test Fire with Temperatures Predicted by DETACT-QS and LAVENT Computer Models*, NISTIR 4947, National Institute of Standards and Technology, January 1993.

[11] Notarianni, K.A. and Davis, W.D., *The Use of Computer Models to Predict Temperatures and Smoke Movement in High Bay Spaces*, NISTIR 5304, National Institute of Standards and Technology, December 1993.

[12] Forney, G.P., Bukowski, R.W., and Davis, W.D., *Field Modeling: Effects of Flat Beamed Ceilings on Detector and Sprinkler Response*, Technical Report - Year 1, National Fire Protection Research Foundation, October 1993.

[13] Walton, W.D. and Budnick, E.K., *Quick Response Sprinklers in Office Configurations: Fire Test Results*, NBSIR 88-3695, National Institute of Standards and Technology, September 1988.

[14] Mathey, R.G., et. al., *Procedures for Sprinkler Anchor Installation on Surfaces with Fireproofing Materials*, NBSIR 87-3676, National Institute of Standards and Technology, February 1988.

[15] Klote, J., et. al., *Staging Areas for Persons with Mobility Limitations*, NISTIR 4770, National Institute of Standards and Technology, October 1990.

[16] Klote, J., et. al., *Feasibility and Design Considerations of Emergency Evacuation by Elevators*, NISTIR 4870, National Institute of Standards and Technology, September 1992.

[17] Stroup, D. W. and Madrzykowski, D., *Conditions in Corridors and Adjoining Areas Exposed to Post-Flashover Room Fires*, NISTIR 4678, National Institute of Standards and Technology, September 1991.

[18] Madrzykowski, D., *The Reduction in Fire Hazard in Corridors Provided by Sprinklers*, NISTIR 4631, National Institute of Standards and Technology, July 1991.

[19] Frable, D. W., *Fire Protection Engineering Assessment Report - Dan Daniels Federal Building, Danville, Virginia*, U. S. General Services Administration, July 1991.

[20] Stroup, D. W. and Levy, S. J., *Fire Safety Report - Klingle Mansion, Washington, DC*, U. S. General Services Administration, January 1991.

Discussion

Ronald Alpert: Did you characterize the heat release rate from these workstations? The peak heat release rate that resulted when you had a successful suppression?

David Stoup: Yes. Typically, the heat release rate was well under 500 kW. We had a shield of fire underneath the work space.